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164065 147

Ninth Type II Quarterly Status
and Technical Progress Report

STUDY ON SPECTRAL/RADIOMETRIC CHARACTERISTICS OF THE THEMATIC MAPPER FOR LAND USE APPLICATIONS

21 September 1984—20 December 1984

WILLIAM A. MALILA
MICHAEL D. METZLER

JANUARY 1985

(E85-10075 NASA-CR-174402) STUDY OF SPECTRAL/RADIOMETRIC CHARACTERISTICS OF THE THEMATIC MAPPER FOR LAND USE APPLICATIONS Quarterly Status Technical Progress Report, 21 Sep. - 20 (Environmental Research Inst. N85-19489

Unclas
G3/43 00075

Contract NAS5-27346
NASA Goddard Space Flight Center
Greenbelt Road
Greenbelt, Maryland 20771

ENVIRONMENTAL
RESEARCH INSTITUTE OF MICHIGAN
BOX 8618 • ANN ARBOR • MICHIGAN 48107

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
164000-14-P		
4. Title and Subtitle Study of Spectral/Radiometric Characteristics of the Thematic Mapper for Land Use Applications		5. Report Date January 1985 6. Performing Organization Code
7. Author(s) William A. Malila and Michael D. Metzler		8. Performing Organization Report No. 164000-14-P
9. Performing Organization Name and Address Environmental Research Institute of Michigan P.O. Box 8618 Ann Arbor, MI 48107		10. Work Unit No. 11. Contract or Grant No. NAS5-27346
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, MD 20771		13. Type of Report and Period Covered Quarterly Status and Technical Progress 21 Sep - 20 Dec 1984 14. Sponsoring Agency Code

15. Supplementary Notes

Mr. Harold Oseroff (Code 902) is serving as Technical Officer and Mssrs. Brian Markham and James Irons (Code 923) are serving as Science Representatives for NASA/GSFC.

16. Abstract

Progress during ERIM's ninth quarter of effort under the Landsat-4 and 5 Image Data Quality Assessment program for the Thematic Mapper is described.

Analyses of Landsat-5 TM radiometric characteristics were performed. Effects which had earlier been found and quantified in Landsat-4 TM data were quantified for Landsat-5 data as well, including:

1) Scan-direction-related signal droop
2) Scan-correlated level shifts

Coincident Landsat-4 and 5 fully corrected (CCT-PT) TM data were analyzed, and band-by-band relationships between the two sensors were derived in terms of both signal counts and radiance.

17. Key Words	18. Distribution Statement
Radiometric Calibration Landsat 4, Landsat 5 Thematic Mapper Noise	Initial distribution is listed at the end of this document.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	30 + iii	

Report No. 164000-14-P

Ninth
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on

Study of Spectral/Radiometric Characteristics of the Thematic Mapper for Land Use Applications

under

Contract NAS5-27346

with

NASA Goddard Space Flight Center
Greenbelt Road
Greenbelt, Maryland 20771

Submitted by

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January 1985

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Ninth Quarterly Report

STUDY OF SPECTRAL/RADIOMETRIC CHARACTERISTICS
OF THE THEMATIC MAPPER FOR LAND USE APPLICATIONS

1. OBJECTIVE

The objective of this investigation is to quantify the performance of the TM as manifested by the quality of its image data in order to suggest improvements in data production and to assess the effects of the data quality on its utility for land resources applications. Three categories of this analysis are: a) radiometric effects, b) spatial effects, and c) geometric effects, with emphasis on radiometric effects.

2. TASKS

Four tasks have been established to address the above objective. The first three are to study radiometric performance, spatial performance, and geometric performance, respectively, while the fourth is to study spectral characteristics. In keeping with the identified objective, the radiometric performance study is our major task.

3. STATUS AND TECHNICAL PROGRESS

During this ninth quarterly reporting period, detailed analyses were performed of Landsat-5 TM radiometric artifacts which were found and reported earlier. 'Droop' effects and scan-related level shifts were quantified using nighttime data. Coincident Landsat-4 and Landsat-5 TM data were compared, and band-by-band correlations were established for the values after radiometric correction.

3.1 PROBLEMS

None.

3.2 ACCOMPLISHMENTS

Accomplishments in two technical areas are described below.

3.2.1 Landsat-5 TM Droop and Level-Shift Artifacts

In the eighth quarterly status report on this contract[1] initial analyses of Landsat-5 TM data were presented which indicated the presence of scan-correlated level-shifts and within-scan 'droop/rise' artifacts similar to those discovered and analyzed for Landsat-4 TM. Continuation of those analyses during the most recent reporting period was directed towards quantifying the effects. As with Landsat-4 TM analyses, reflective-band (Bands 1-5 and 7) data collected during the nighttime passes proved most useful in quantifying these relatively low-level effects. The earlier work with Landsat-4 TM showed that the time constants computed for daytime and nighttime scenes were very similar to each other on a band-by-band basis.

Within-Line Droop. A within-line 'droop' of mean signal level ('rise' in nighttime data) was observed earlier in both Landsat-4 TM data[2] and Landsat-5 TM data[1], and was quantified for the Landsat-4 TM[3,4]. The single nighttime Landsat-5 TM scene (ID 5-0052-02182, Harrisburg) available to us was used to quantify the effect in Landsat-5 TM.

As done previously, 'average' scan-lines were computed by first dividing the image data into forward-scan and reverse-scan scenes, then computing average signal values for each pixel position in the scan. These 'average' Landsat-5 TM nighttime scan-lines are illustrated in Figures 1(a)-(f), along with data from Landsat-4 TM for comparison. The y-axes all have the same scale, i.e. 0.1 DN full scale, to facilitate comparison between bands and sensors. In general, the within-scan 'rise' has the same magnitude and time constant for the same band in each sensor. Note that for reverse scans, pixel position 6000 is sampled prior to pixel position 1. Therefore the effect is seen to be a signal 'rise' with increasing time for both forward and reverse scans.

Band 1 displays the greatest effect, with the mean reverse-scan signal increasing approximately 0.1 DN during the active scan. Fitting a simple exponential decay model to this effect indicated a time constant (time for magnitude of effect to decay to $1/e$ of original value) of 900-1000 pixels[4].

Since the magnitude and time constant of the nighttime within-scan 'rise' are essentially identical for Landsats-4 and 5 TM, we expect the daytime 'droop' effects to be similar also. During daylight data acquisition when signal levels are much higher, we observed in Landsat-4 TM data a similar increase in the magnitude of the 'droop' effect. At night, the magnitude is <0.1 DN, with a time constant of

900-1000 pixels. The mean scene level at night is 2.0-2.4 DN. In a daytime Band 1 scene (ID 4-0049-16262) which had a scene mean of 61.9 DN, the magnitude of the 'droop' was observed to be approximately 1.0-1.5 DN, still with a time constant of 900-1000 pixels. Quantification of this effect in daytime Landsat-5 TM data awaits analysis of an appropriate scene in which variations in scene radiance have a relatively uniform spatial distribution.

While the magnitude of the effect does not appear to be strictly proportional to the scene mean, it does appear as if the 'droop' or 'rise' is a drift toward the 'grand mean' signal of the scene, a mean which includes the minor frames during shutter obscuration, calibration pulse, and DC restore. This 'grand mean' would be lower than the scene mean during the daytime due to the addition of the data acquired during shutter obscuration, and would be greater than the scene mean during nighttime data acquisition, where the scene itself is effectively a continuation of the shutter obscuration, and the calibration pulses drive the 'grand mean' to a level slightly higher than the scene mean. Further analyses are planned to test this hypothesis.

This 'droop/rise' effect has been observed for the Primary Focal Plane Bands only. In both Landsats-4 and 5 TM, Bands 5 and 7 show essentially no change in mean signal level within the scan line, with perhaps a slight change in the *opposite* direction to that seen in Bands 1-4. Band 6 mean signal levels have been observed to change within scan lines in a variety of patterns. Detailed analysis of potential within-scan effects in Band 6 is made more difficult by the absence of any constant scene data comparable to the nighttime data in the reflective bands. Even a completely uniform ground scene would have varying atmospheric effects in different parts of the scene.

Scan—Correlated Level Shifts. In Landsat-4 data an effect was analyzed which changed the signal level of all samples within a scan-line or group of scan-lines by up to 2.0 DN[3]. The changes were aperiodic, occurring at random intervals with the level shifting during mirror turn-around time. All affected detectors shifted levels at the same time, with the level shifts following one of two patterns (most detectors exhibited both patterns, but one was dominant). One pattern was exemplified by Band 1 Detector 4, the other by Band 7 Detector 7. A complete description of this effect in Landsat-4 TM data, including magnitudes and phase relationships for all reflective-band detectors, is contained in our fifth quarterly status report[5].

Initial analyses of Landsat-5 TM data indicated a similar effect, but with only one pattern[1,6]. We examined nighttime reflective-band data to provide quantification of the magnitude and phase relationships of the effect. Figures 2(a)-(f) illustrate the level shifts for the reflective bands in Landsat-5 TM. The plots were produced by computing the mean signal level for each scan for each detector of each band, and plotting these scan-line means vs the scan number. Relative magnitudes and phases are readily apparent from the illustrations. Table 1 provides the quantitative results. It can be seen that nearly all detectors are affected, although the magnitude is very low (<0.1 DN) for many. Band 3 shows the greatest effect, although Band 2 Detector 1 is the single most affected detector with a level shift >0.5 DN. This compares with the shift of 2.0 DN measured for

Landsat-4 Band 1 Detector 4. Several detectors did not display any measurable effect in this scene. They are: Band 1 Detectors 1, 3, 5, 9, 13, and 15, Band 2 Detector 4, Band 4 Detectors 8, 10, 12, and 16, Band 5 Detectors 2, 4, 7, 10, amd 13, and Band 7 Detectors 1, 2, 5, and 15. As seen in Landsat-4 TM data, patterns of phase and magnitude of the level-shift effect within a band often place the detectors into odd/even groups. As with the within-line 'droop', the confounding effect of scene data prevents analysis of this type for Band 6. For this band, shutter data may be used to provide similar results, but with slightly lower precision.

Methods of correcting for level shifts have been proposed which appear effective at reducing the effect[6-11].

3.2.2 TM Landsat-4 vs Landsat-5 Radiometric Comparison

In the previous quarterly report we presented a comparison of Landsat-4 and Landsat-5 TM radiometry derived from raw (radiometrically uncorrected) data. The relationships between like bands were found to be quite linear, and in general had near-unity gains and near-zero offsets, indicating very similar detector responses between the two sensors. The most striking exception was the relationship between Band 6 of the two sensors: although the relationship between the two sensors was linear, Band 6 of Landsat-5 TM had a gain of less than half that of Landsat-4 Band 6. This presumably was due to the fact that the Landsat-5 TM was not fully cooled to its recommended operating temperature when this experimental data set was collected, and had been allowed only a two week outgas period prior to being activated.

With the receipt of radiometrically corrected data from the coincident Landsat-4 and 5 TM scenes, the band-by-band comparison of the two sensors was performed again. As before, relatively homogeneous regions were found in each band for one scene (i.e., 4-0608-15463), the same region was identified in the other scene (5-0014-15460), mean signal values were computed for each region of each scene, and regression analyses were performed on a band-by-band basis. The regression and correlation coefficients are presented in Table 2, Figures 3(a)-(g) illustrate the relationships between radiometrically similar wavebands.

As with the radiometrically uncorrected data, the relationships between like bands of the two sensors are quite linear. An unexpected result was the existance of non-unity gains, non-zero offsets, and non-matching data ranges. The Landsat-5 TM gain terms are different from the corresponding Landsat-4 terms by +1%, +6%, −6%, −1%, +9%, −5%, and +3% in Bands 1-7, respectively. Since both the Landsat-4 and Landsat-5 scenes were processed through TIPS, it would be expected that radiometrically corrected products would have essentially identical corrected signal values for the same scene viewed at the same time.

Converting the pixel values to radiance levels via the coefficients provided in the Radiometric Calibration Ancillary Record of the Leader File associated with each band of image data[12] did not resolve the discrepancy observed between the two sensors. Table 3 lists the gain and offset values extracted from tape headers and used in the conversion; Table 4 details the relationships between the two sensors in terms of radiance. It is not known at this time why the radiometrically corrected data are not more closely matched — further investigation will seek a better understanding of the mismatch.

An additional discrepancy was noted between the published Band 6 temperature sensitivity range and the range implied by the gain and offset values listed in Table 3. Using these gain and offset values to convert the range 0-255 DN to radiance gives a radiance range of 0.125 to 1.575 mW/cm²-sr-μm, representing an apparent temperature range of approximately 200 to 340°Kelvin, not the advertised 260K to 320K. This causes an increase in the temperature difference represented by a change of 1 DN. The specified 260K to 320K temperature range actually spans approximately 63-196 DN vs the specified 0-255 DN. For Landsat-5 TM, the radiance range is very slightly different (0.124 to 1.560 mW/cm²-sr-μm), still giving a range of apparent temperature of approximately 200K to 340K (or a DN range of approximately 63-193 for apparent temperatures of 260K to 320K). Users unaware of this change may incorrectly interpret temperatures derived from TM Band 6 data.

3.3 SIGNIFICANT RESULTS

Summarizing the significant results of work performed during this reporting period:

(a) Landsat-5 TM reflective-band data were found to exhibit 'droop' characteristics essentially identical to those reported for Landsat-4 TM.

(b) Scan-correlated level shifts were quantified for all reflective-band detectors in Landsat-5 TM; the maximum shifts were measured at approximately 0.5 DN.

(c) Radiometric comparisons were established between radiometrically corrected TM data from coincident scenes of Landsat-4 and Landsat-5; differences were found and are being investigated.

(d) Radiance conversion coefficients provided with Band 6 data imply a temperature range associated with 0-255 DN of 200K to 340K instead of the specified 260K to 320K. This change can have significant impact on the unaware user.

3.4 PUBLICATIONS AND PRESENTATIONS

None.

3.5 RECOMMENDATIONS

No additional major recommendations beyond those made in previous reports are identified at this time.

3.6 FUNDS EXPENDED

3.7 DATA RECEIPTS

Raw data tapes (unity RLUT CCT-AT) and calibration data tapes (CALDUMP) were received during this quarter for the following scenes:

San Francisco	P44/R34	5-0126-18143
Iowa	P28/R30	5-0158-16350

Fully corrected data (CCT-PT) were received for two scenes:

Alabama	P20/R37	5-0014-15460
White Sands	P33/R37	5-0129-17075

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Table 1. MAGNITUDE OF LEVEL SHIFTS FOR NIGHT SCENE 5-0052-02182

Band	Det	Amplitude	Separation of States (Number of Std. Dev.)	Band	Det	Amplitude	Separation of States (Number of Std. Dev.)
1	1	0.038	0.9	4	1	0.285	11.0
1	2	-0.229	8.4	4	2	0.150	5.5
1	3	0.068	1.7	4	3	0.149	5.0
1	4	-0.184	4.2	4	4	0.205	8.4
1	5	0.044	1.3	4	5	0.044	3.3
1	6	-0.249	6.3	4	6	0.045	2.5
1	7	0.113	3.4	4	7	0.025	3.1
1	8	-0.208	5.2	4	8	0.016	0.6
1	9	0.042	1.3	4	9	0.078	2.8
1	10	-0.303	9.3	4	10	0.004	0.3
1	11	0.068	2.3	4	11	0.106	3.8
1	12	-0.216	5.4	4	12	0.016	0.7
1	13	-0.010	0.3	4	13	0.138	4.4
1	14	-0.307	8.5	4	14	0.081	2.2
1	15	0.001	0.0	4	15	0.085	3.0
1	16	-0.288	7.6	4	16	0.013	0.5
2	1	0.523	16.3	5	1	0.135	6.8
2	2	0.084	4.8	5	2	0.006	0.4
2	3	0.239	11.5	5	3	0.190	13.6
2	4	-0.009	1.1	5	4	-0.023	1.7
2	5	0.178	19.5	5	5	-0.067	4.5
2	6	0.070	7.2	5	6	-0.128	9.3
2	7	0.157	8.7	5	7	0.008	0.6
2	8	0.065	7.3	5	8	-0.115	9.0
2	9	0.079	8.2	5	9	0.058	4.3
2	10	0.012	2.4	5	10	0.019	0.5
2	11	0.086	6.9	5	11	0.100	7.4
2	12	0.018	2.3	5	12	-0.129	6.9
2	13	0.177	9.5	5	13	0.022	1.7
2	14	0.075	8.4	5	14	-0.074	5.0
2	15	0.159	10.1	5	15	-0.088	7.4
2	16	0.263	12.6	5	16	-0.137	9.7
3	1	0.470	14.1	7	1	0.019	1.1
3	2	0.196	8.1	7	2	-0.013	0.8
3	3	0.437	14.3	7	3	-0.050	3.1
3	4	0.389	13.9	7	4	-0.110	6.6
3	5	0.317	8.2	7	5	0.001	0.1
3	6	0.340	12.0	7	6	-0.095	6.6
3	7	0.286	7.8	7	7	0.148	8.9
3	8	0.141	8.5	7	8	-0.159	10.2
3	9	0.326	10.5	7	9	0.161	11.7
3	10	0.250	9.4	7	10	-0.156	9.4
3	11	0.371	12.9	7	11	0.107	7.0
3	12	0.351	11.8	7	12	-0.060	4.1
3	13	0.318	12.8	7	13	0.032	2.3
3	14	0.237	7.7	7	14	-0.038	2.1
3	15	0.321	12.6	7	15	0.022	1.6
3	16	0.257	11.8	7	16	-0.116	8.0

** Negative amplitudes indicate level shifts with phase shifts of 180° relative to Band 3 detectors.

TABLE 2. Landsats−4 and 5 TM Regressions of Digital Values (Scenes 4−0608−15463 and 5−0014−15460, 15 March 1984)

Landsat-5 TM = A*(Landsat-4 TM) + B

Band	A (Gain)	B (Offset)	S.E.	R^2	Range of Data Values (DN) Landsat-4	Landsat-5
1	1.0083	−1.580	0.351	0.9982	76-100	76-100
2	1.0634	−0.976	0.548	0.9978	24-51	25-53
3	0.9418	−2.244	0.668	0.9970	26-65	23-59
4	0.9865	−3.326	1.172	0.9961	12-74	7-69
5	1.0920	−2.094	2.154	0.9942	6-127	2-135
6	0.9467	6.845	1.941	0.9693	114-146	115-145
7	1.0330	−3.843	1.384	0.9962	4-74	0-73

TABLE 3. Landsats−4 and 5 TM Radiance Conversion Parameters (Scenes 4−0608−15463 and 5−0014−15460, 15 March 1984)

Radiance = $A0$ + $A1$*DN (mW/cm²-sr-µm)

Band	$A0$ (mW/cm²-sr-µm) Landsat-4	Landsat-5	$A1$ (mW/cm²-sr-µm)/DN Landsat-4	Landsat-5
1	−0.1500	−0.1500	0.06024	0.06024
2	−0.2802	−0.2805	0.11750	0.11750
3	−0.1203	−0.1194	0.08061	0.08059
4	−0.1504	−0.1500	0.08145	0.08143
5	−0.0372	−0.0370	0.01081	0.01081
6	0.1252	0.1238	0.00569	0.00563
7	−0.1500	−0.1500	0.00570	0.00568

TABLE 4. Landsats-4 and 5 TM Regressions of Radiance Values (Scenes 4-0608-15463 and 5-0014-15460, 15 March 1984)

Landsat-5 TM = A*(Landsat-4 TM) + B

Band	A (Gain)	B (Offset)	S.E.	R^2	Range of Radiance Values (mW/cm^2-sr-µm) Landsat-4	Landsat-5
1	1.0083	−0.095	0.021	0.9982	4.4-5.9	4.4-5.9
2	1.0634	−0.097	0.064	0.9978	2.6-5.7	2.7-6.0
3	0.9420	−0.189	0.054	0.9970	2.0-5.2	1.7-4.6
4	0.9867	−0.273	0.095	0.9961	0.8-5.9	0.4-5.5
5	1.0920	−0.023	0.023	0.9942	0.0-1.3	0.0-1.4
6	0.9556	0.039	0.011	0.9693	0.8-1.0	0.8-1.0
7	1.0356	−0.022	0.008	0.9962	0.0-0.4	0.0-0.4

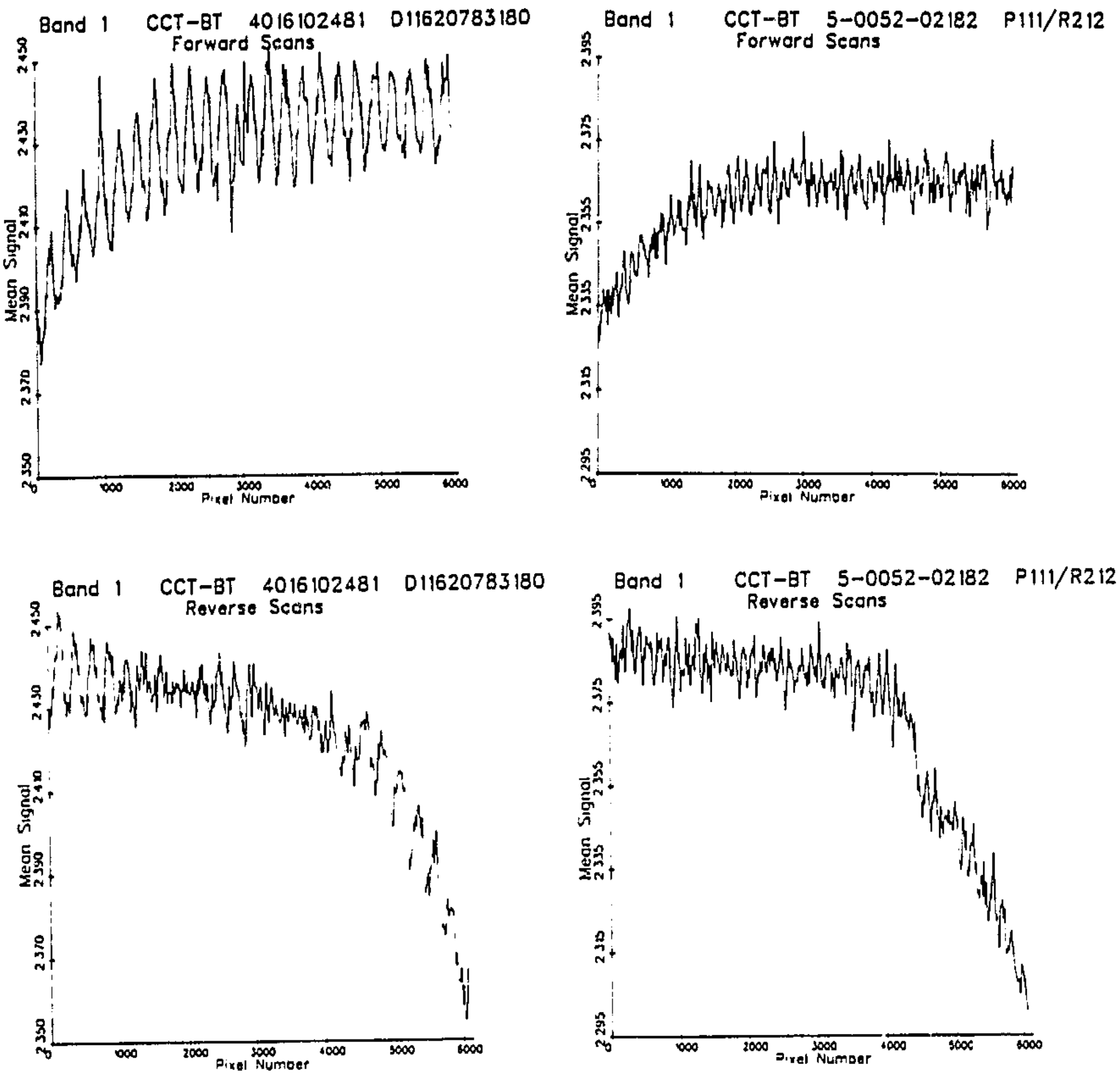

Figure 1(a). LANDSATS-4 AND 5 NIGHTTIME DROOP EFFECT – BAND 1

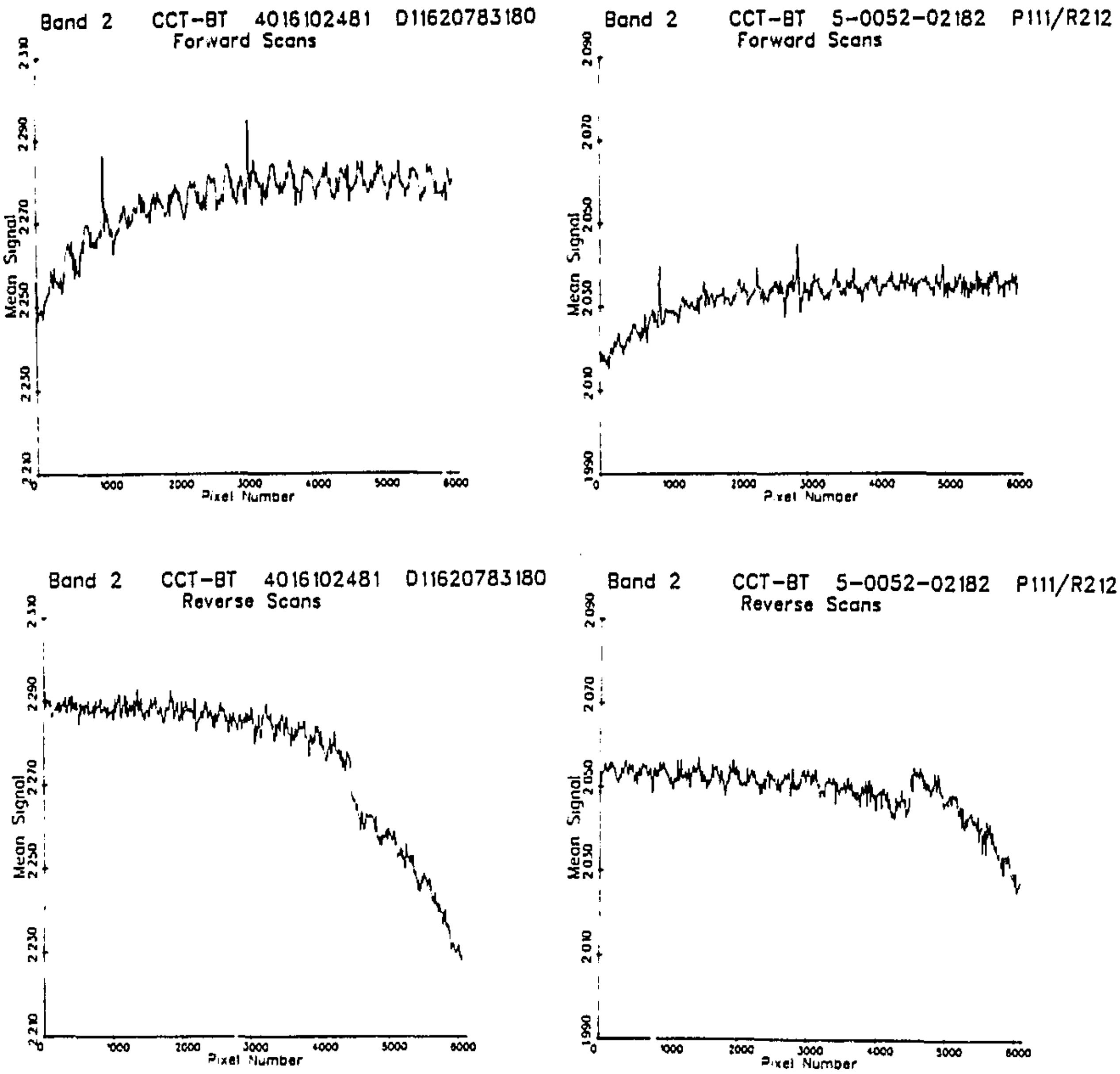

Figure 1(b). LANDSATS-4 AND 5 NIGHTTIME DROOP EFFECT – BAND 2

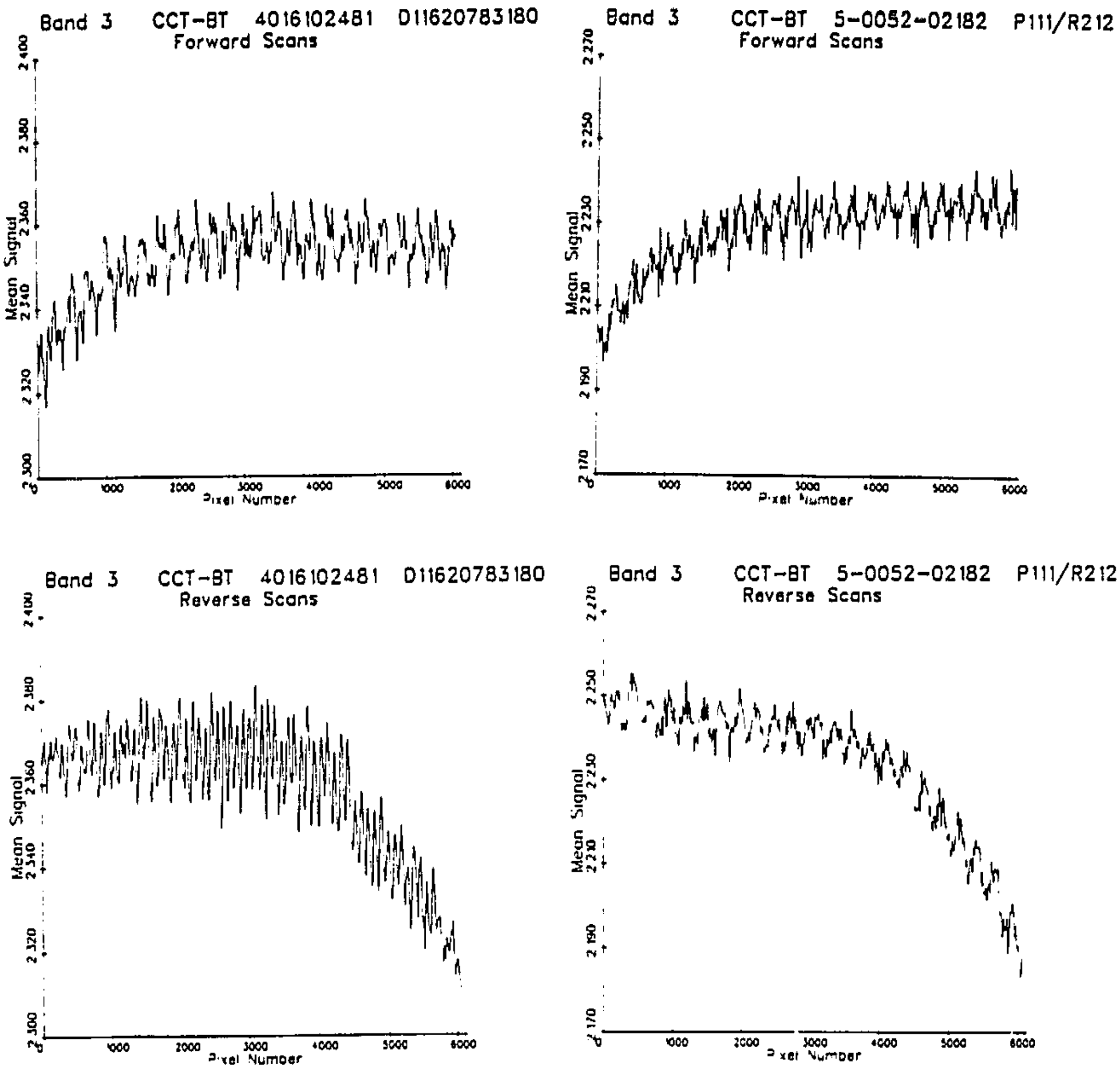

Figure 1(c). LANDSATS-4 AND 5 NIGHTTIME DROOP EFFECT – BAND 3

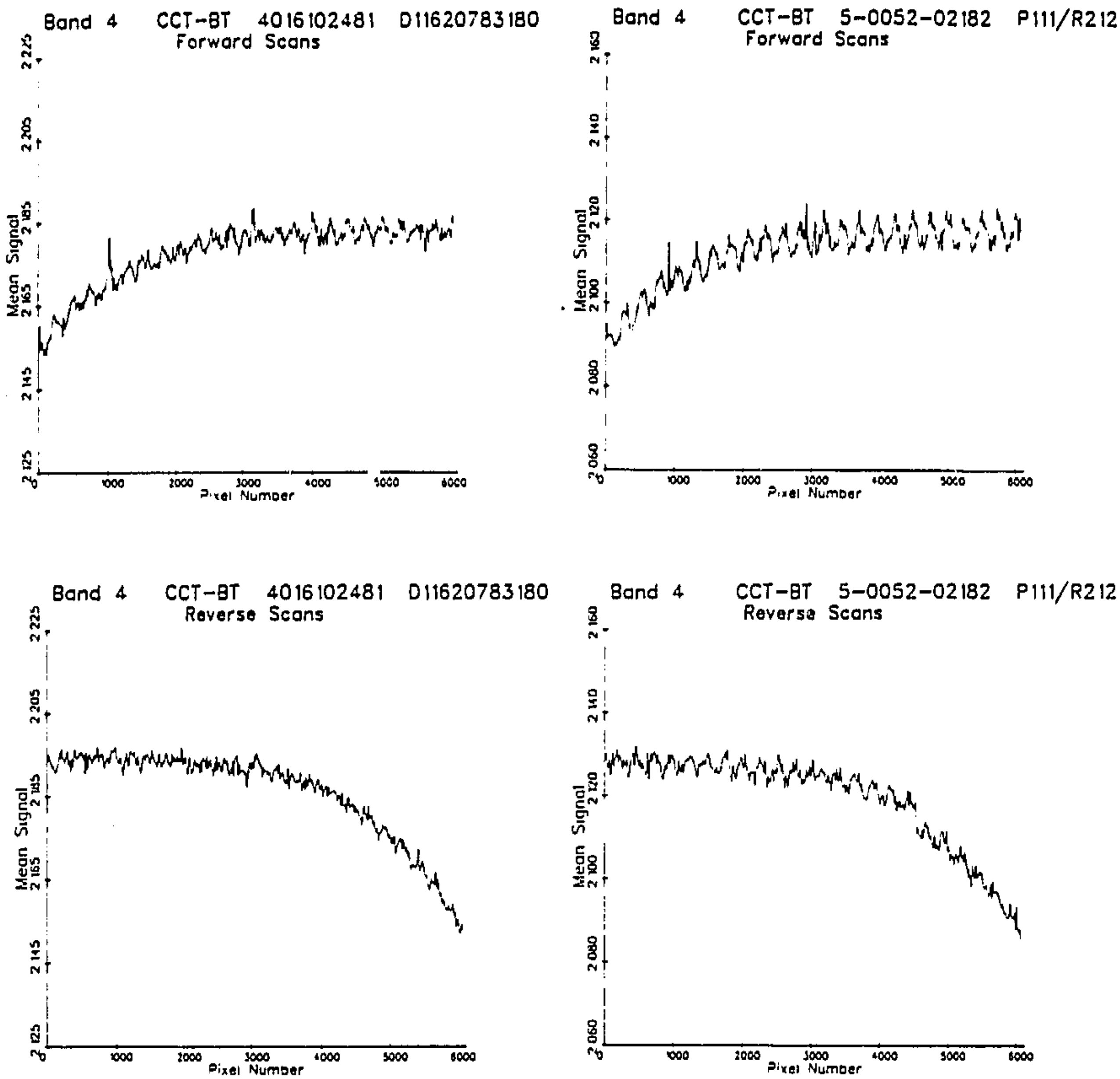

Figure 1(d). LANDSATS-4 AND 5 NIGHTTIME DROOP EFFECT – BAND 4

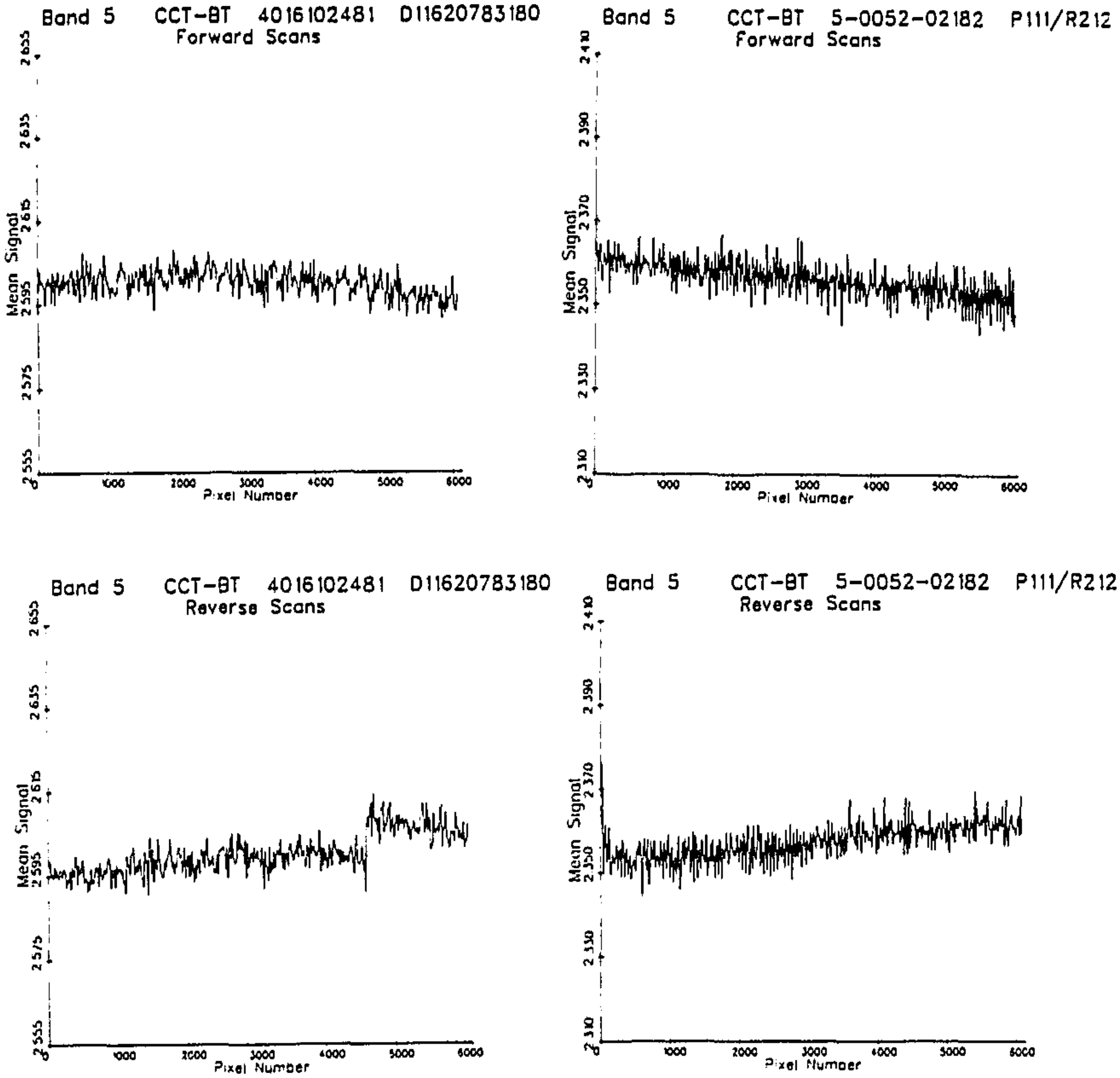

Figure 1(e). LANDSATS-4 AND 5 NIGHTTIME DROOP EFFECT – BAND 5

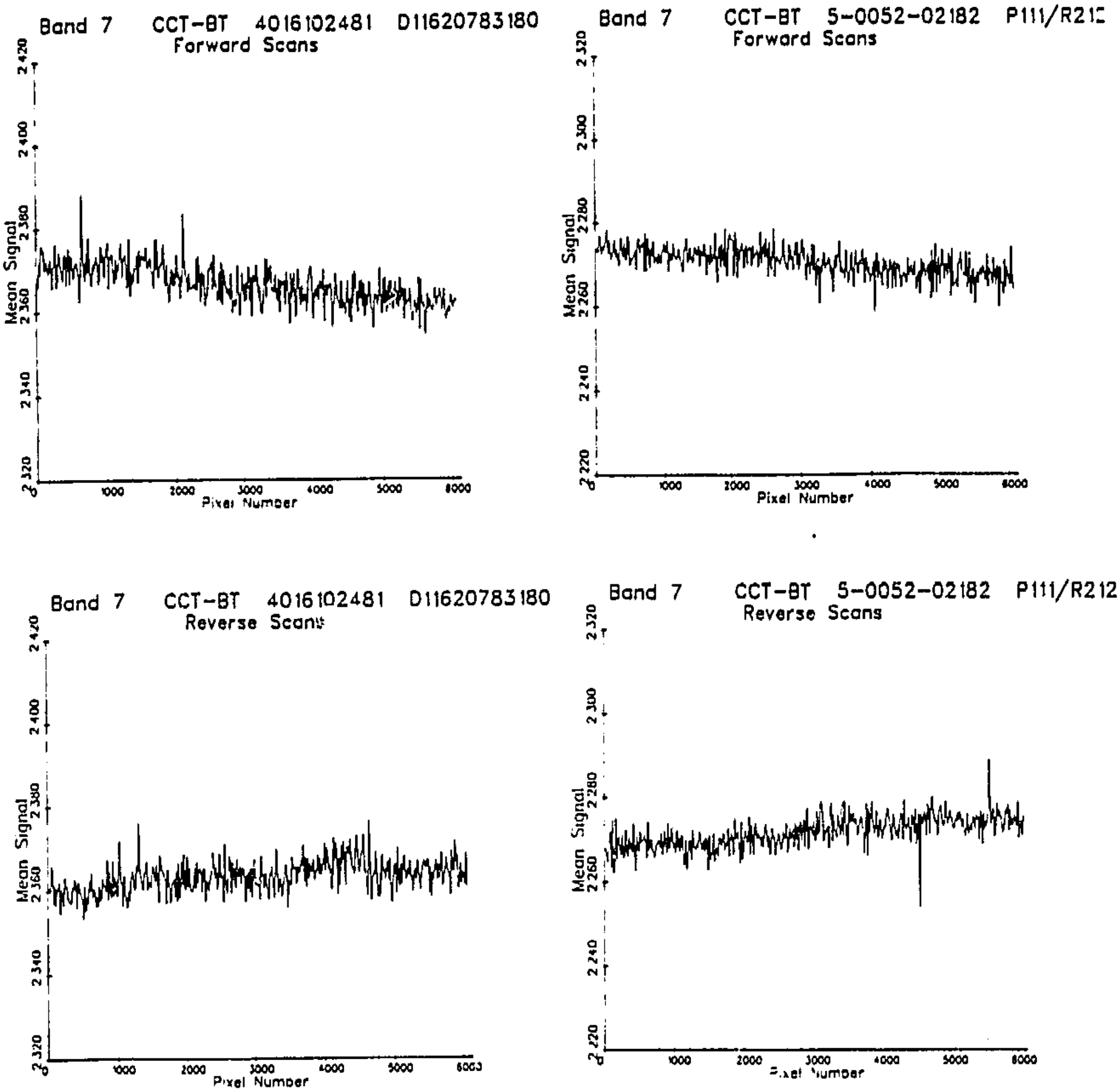

Figure 1(f). LANDSATS-4 AND 5 NIGHTTIME DROOP EFFECT — BAND 7

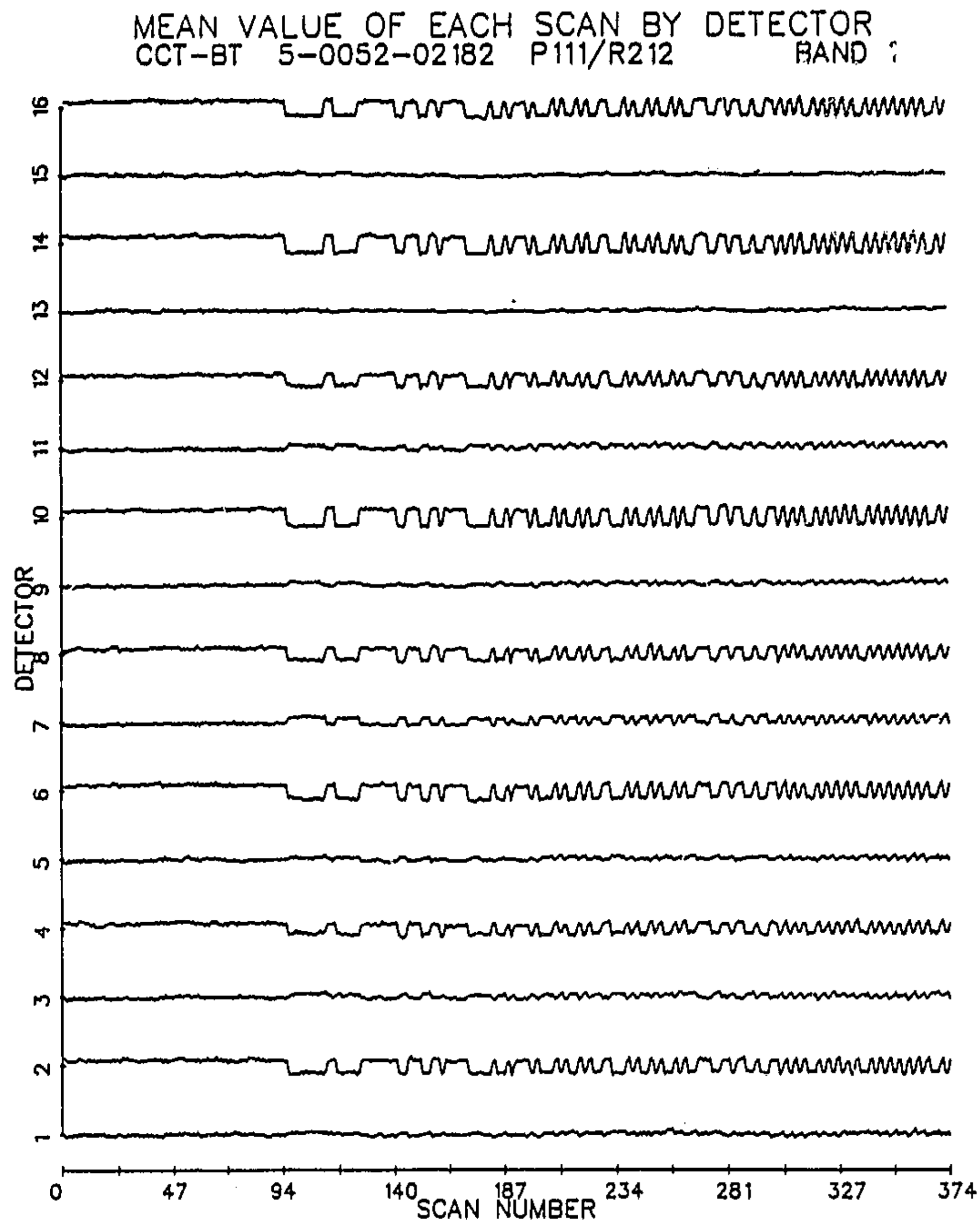

Figure 2(a). LANDSAT-5 SCAN-CORRELATED LEVEL SHIFTS — BAND 1

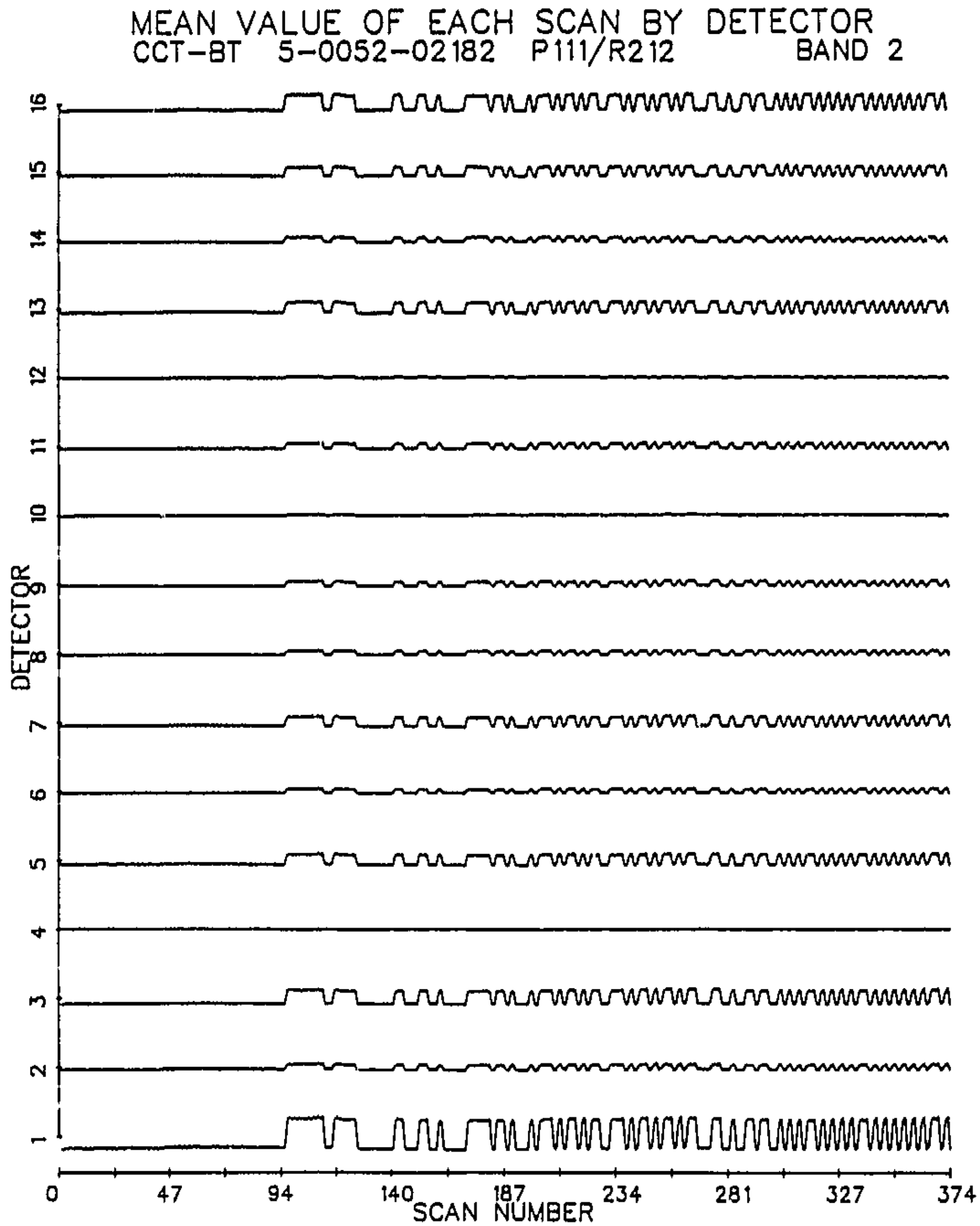

Figure 2(b). LANDSAT-5 SCAN-CORRELATED LEVEL SHIFTS – BAND 2

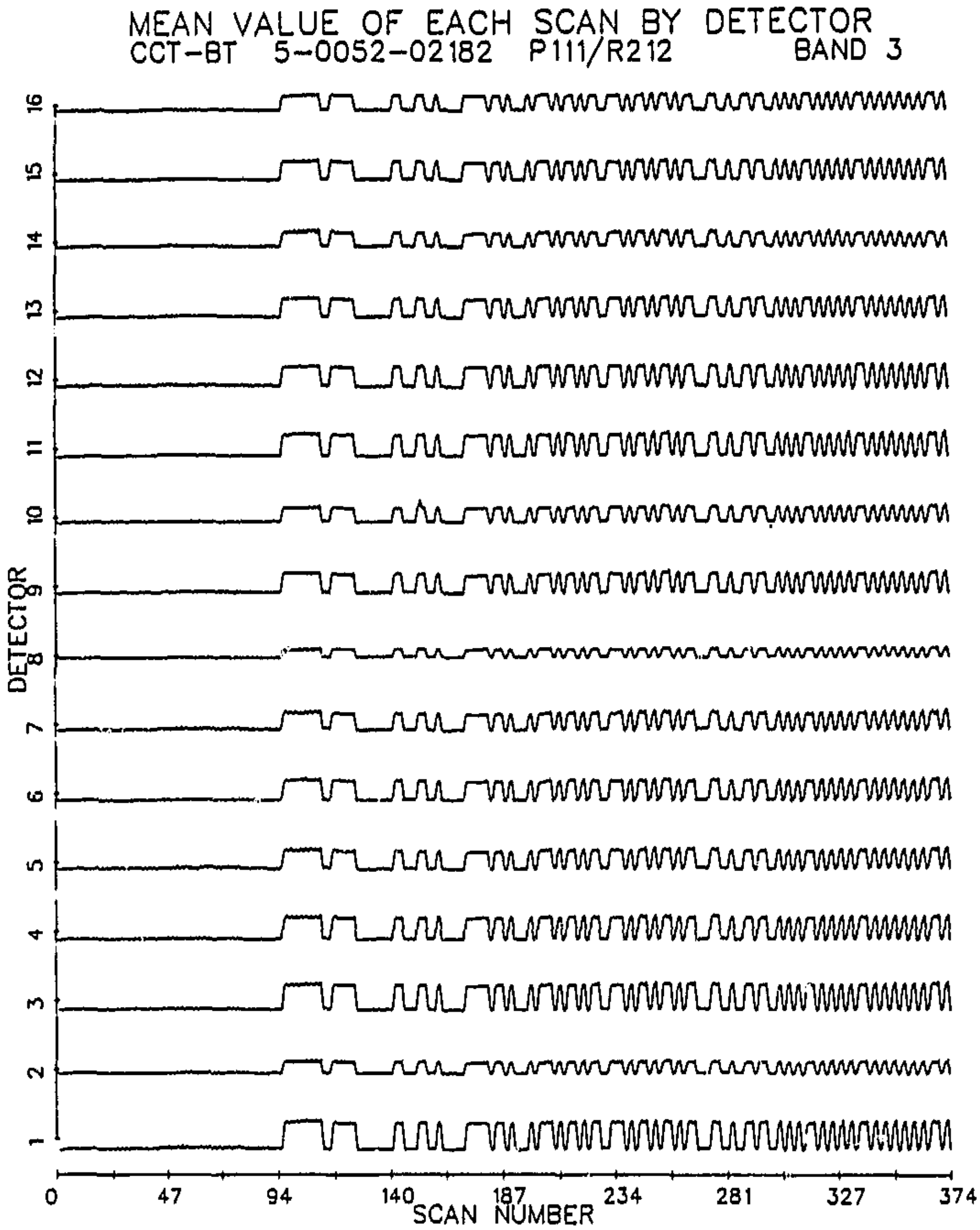

Figure 2(c). LANDSAT-5 SCAN-CORRELATED LEVEL SHIFTS – BAND 3

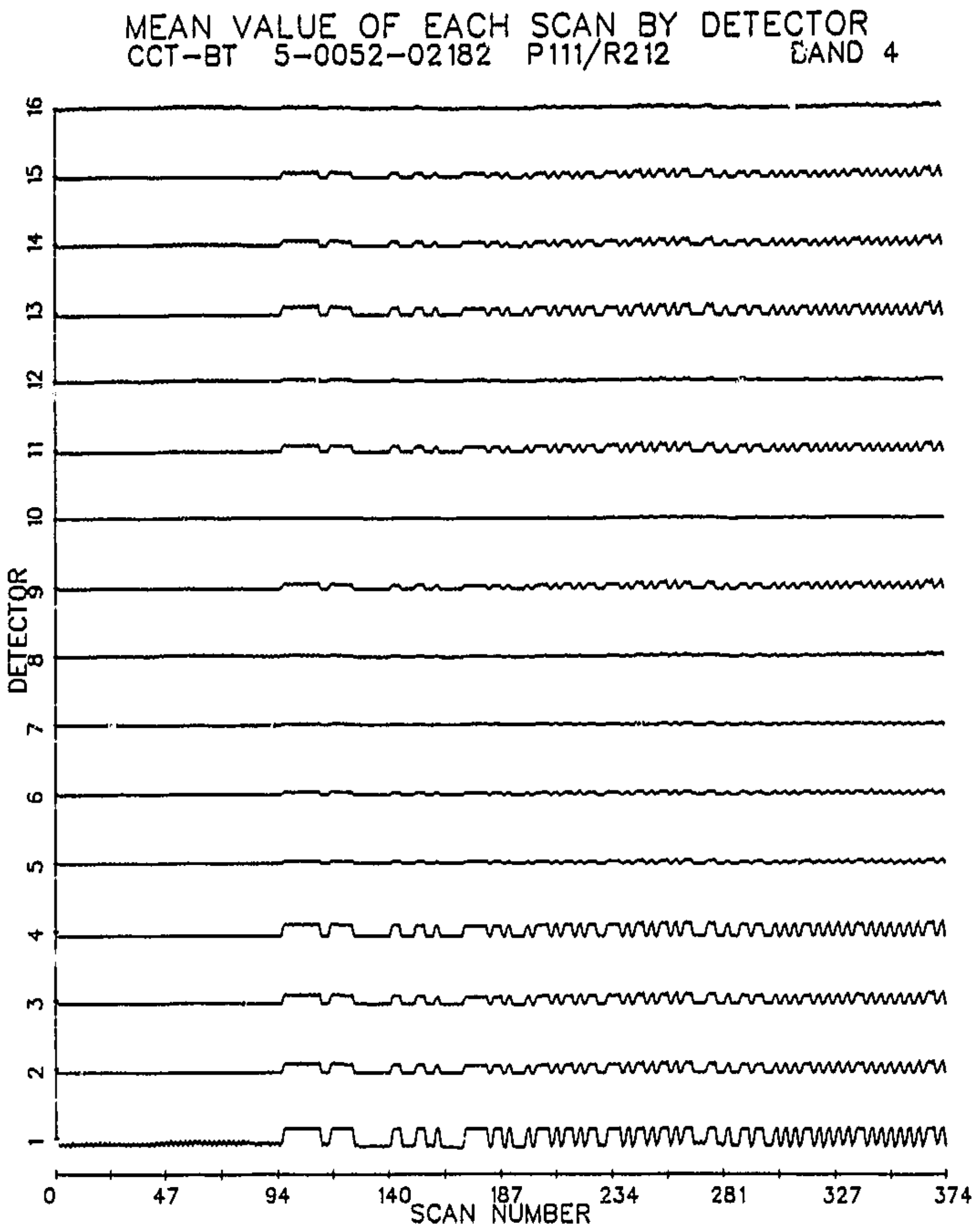

Figure 2(d). LANDSAT-5 SCAN-CORRELATED LEVEL SHIFTS - BAND 4

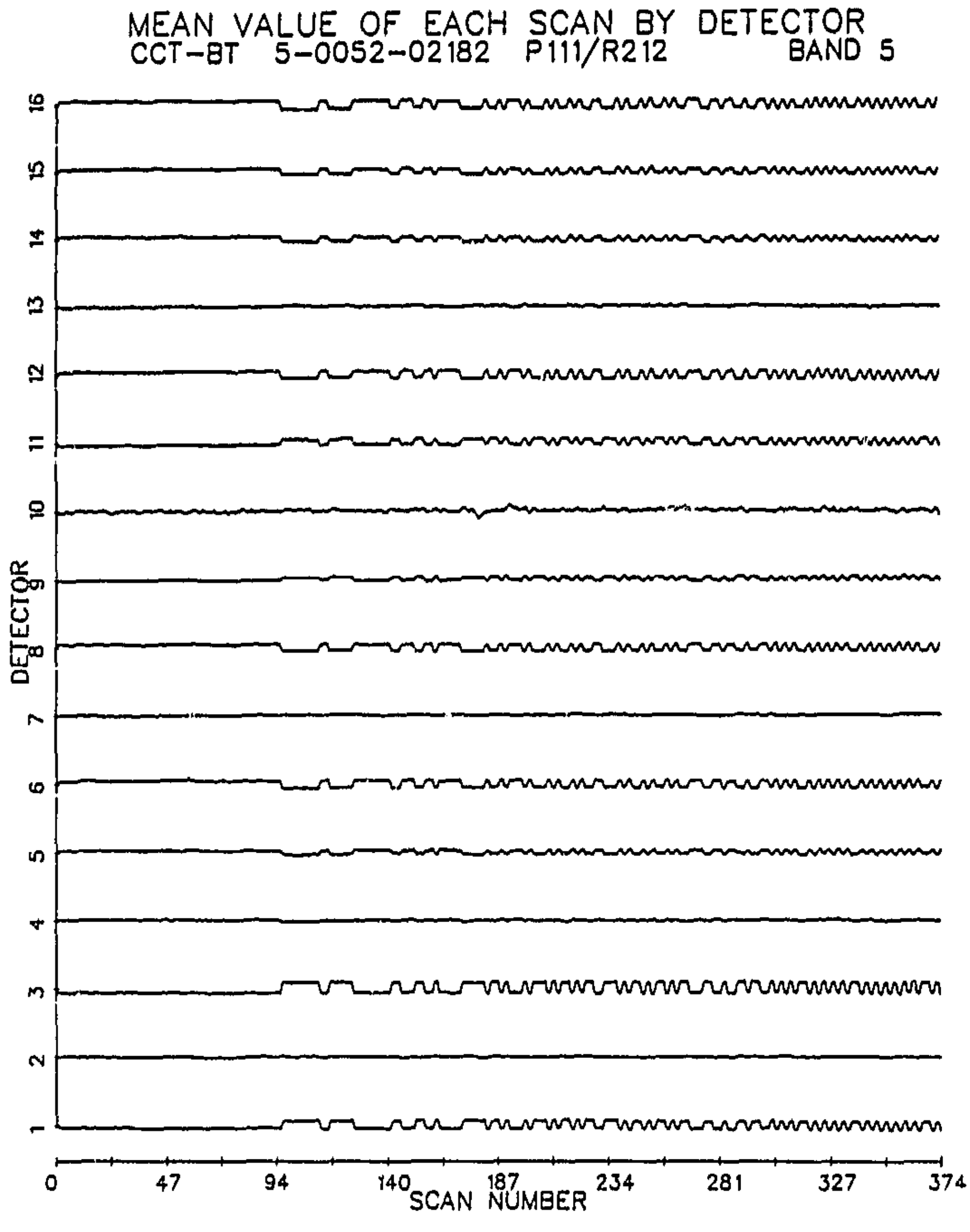

Figure 2(e). LANDSAT-5 SCAN-CORRELATED LEVEL SHIFTS - BAND 5

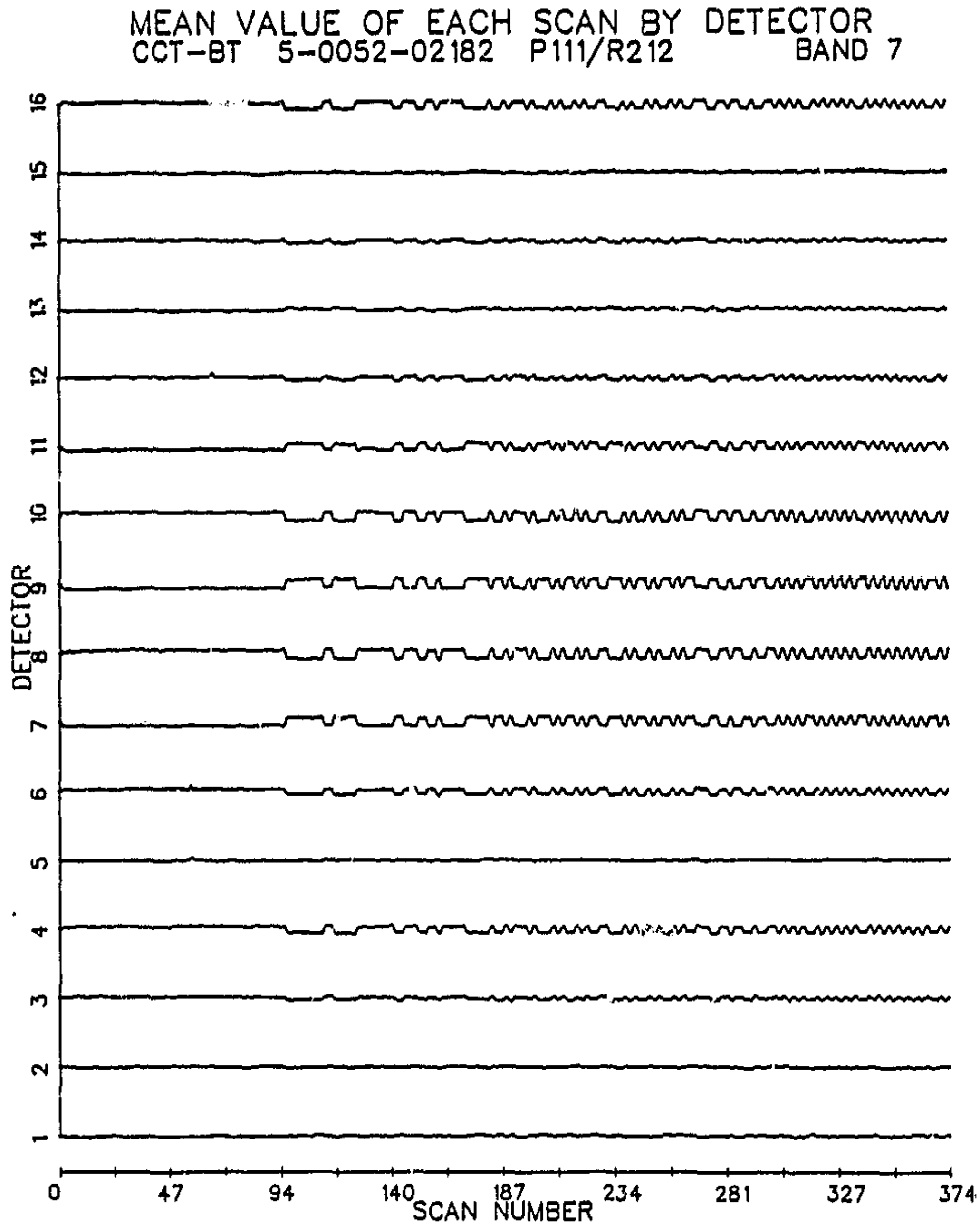

Figure 2(f). LANDSAT-5 SCAN-CORRELATED LEVEL SHIFTS - BAND 7

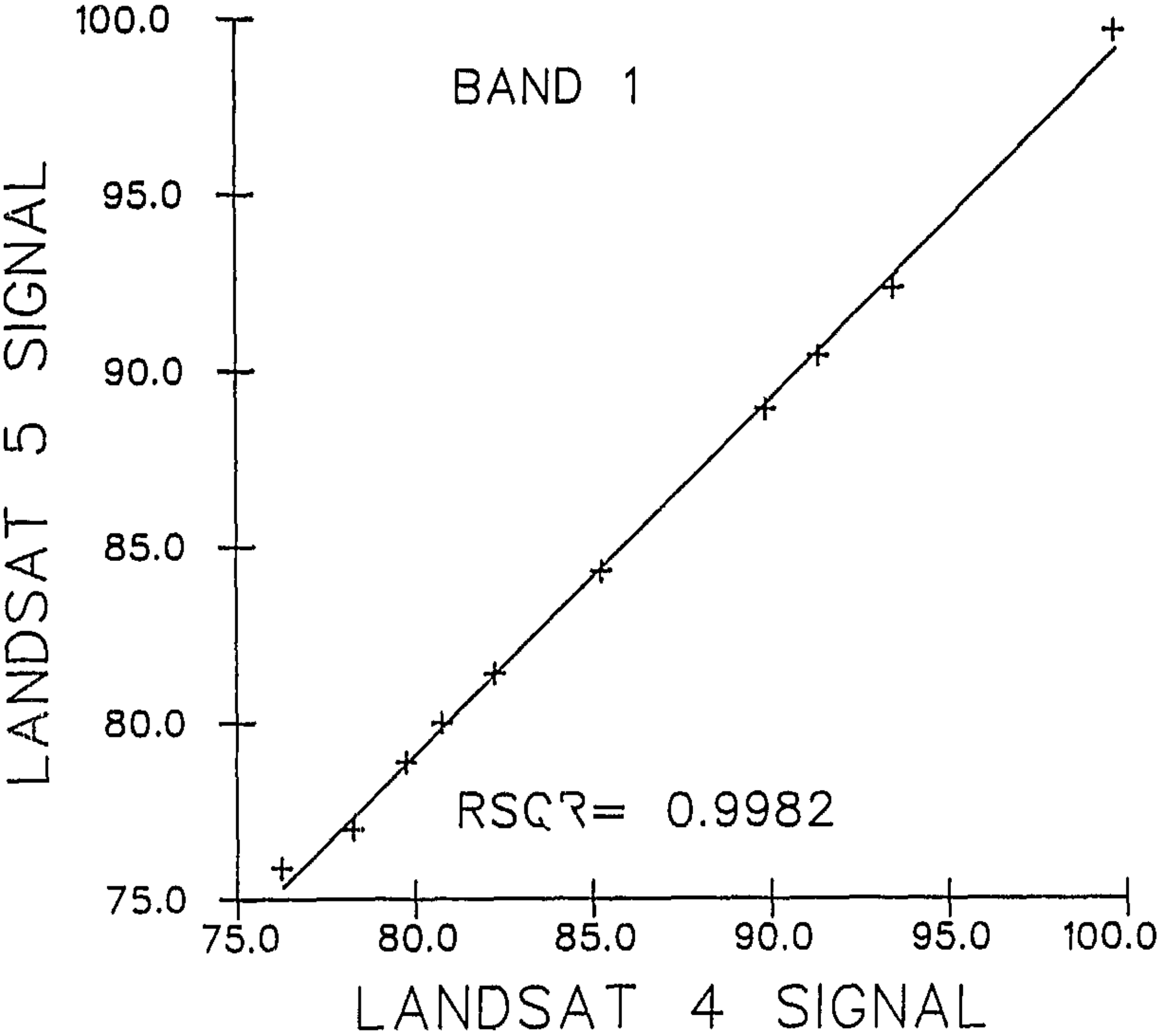

Figure 3(a). RELATIONSHIP BETWEEN LANDSATS-4 AND 5 TM CORRECTED DATA – BAND 1

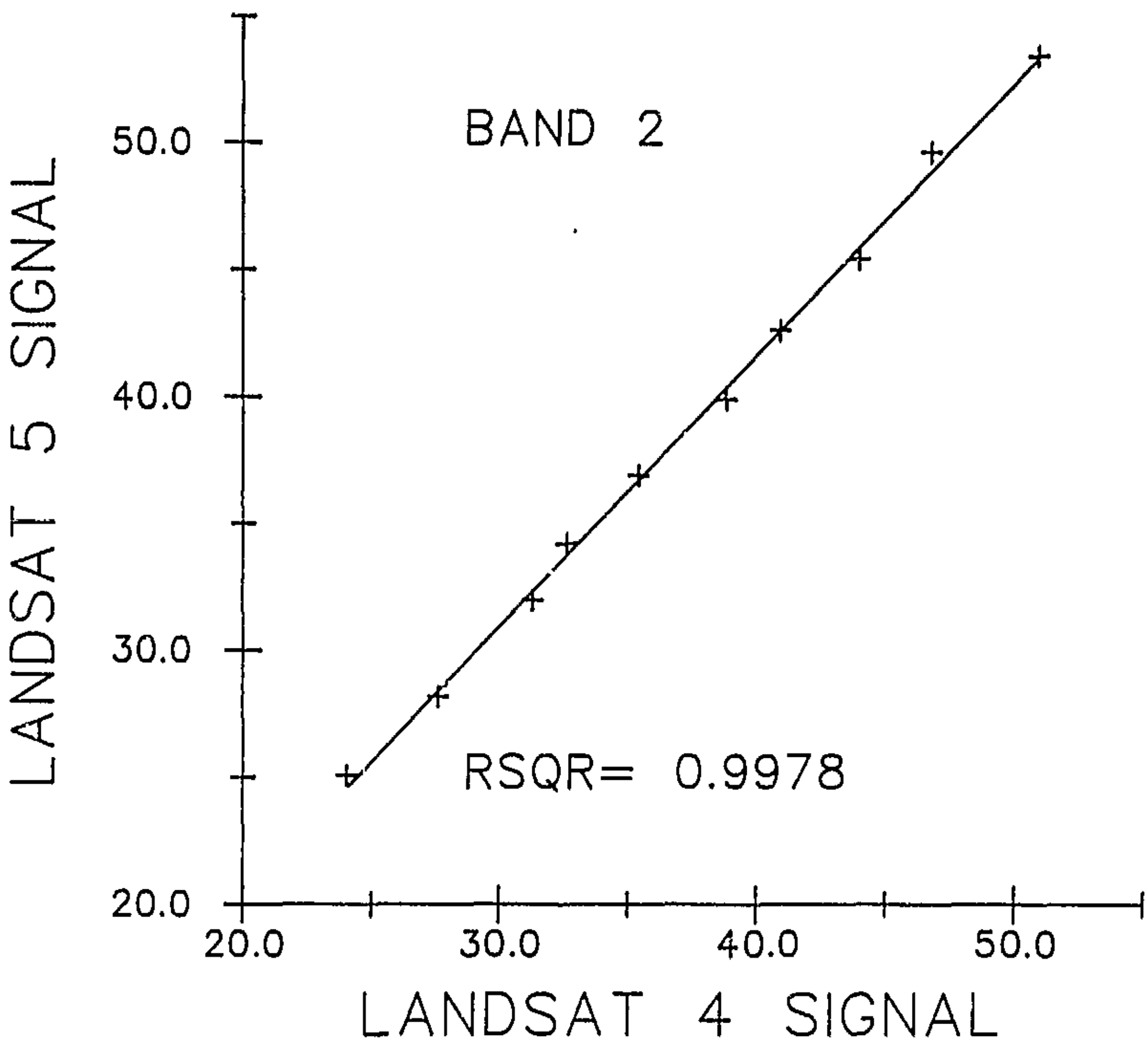

Figure 3(b). RELATIONSHIP BETWEEN LANDSATS-4 AND 5 TM CORRECTED DATA – BAND 2

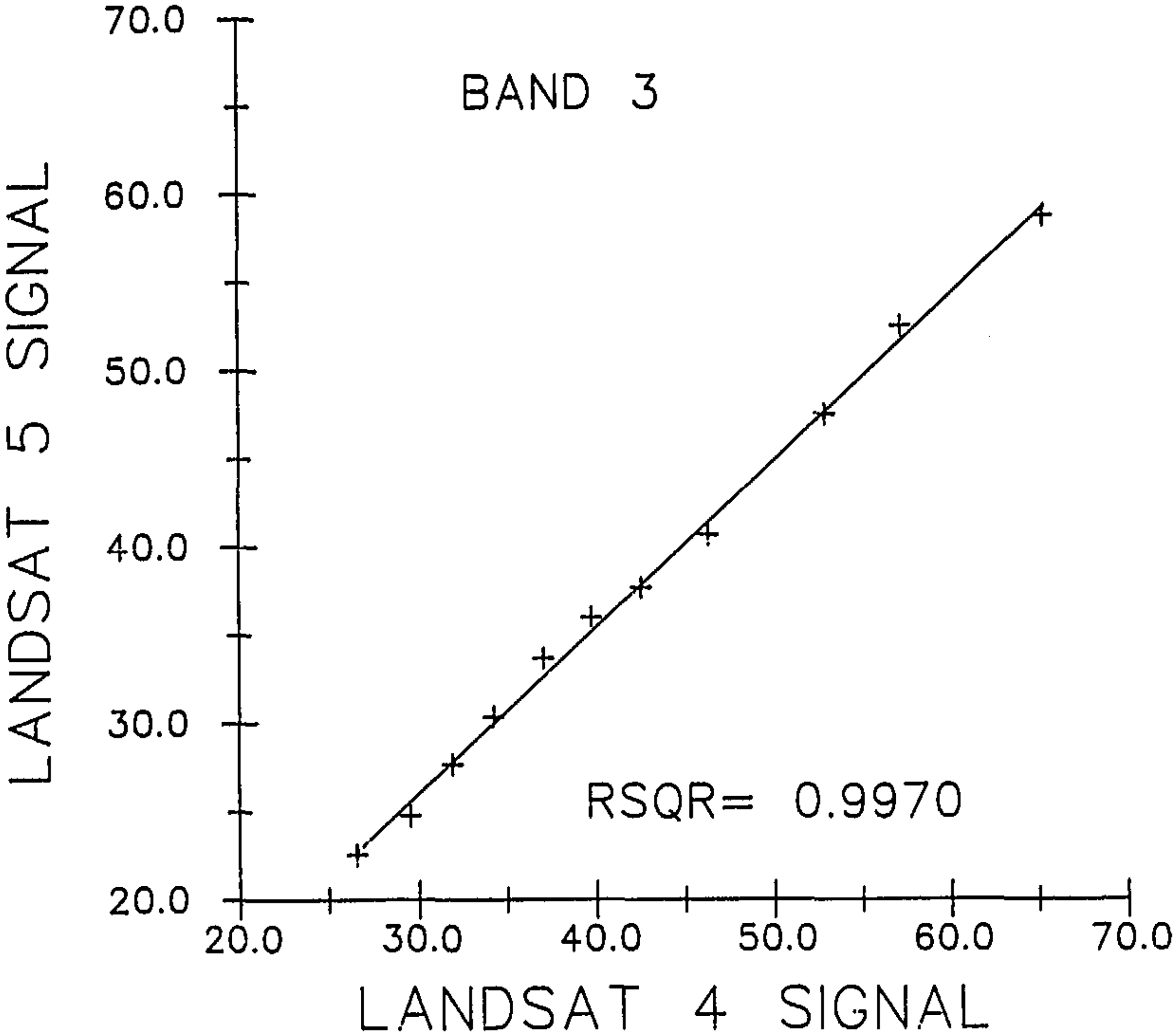

Figure 3(c). RELATIONSHIP BETWEEN LANDSATS-4 AND 5 TM CORRECTED DATA – BAND 3

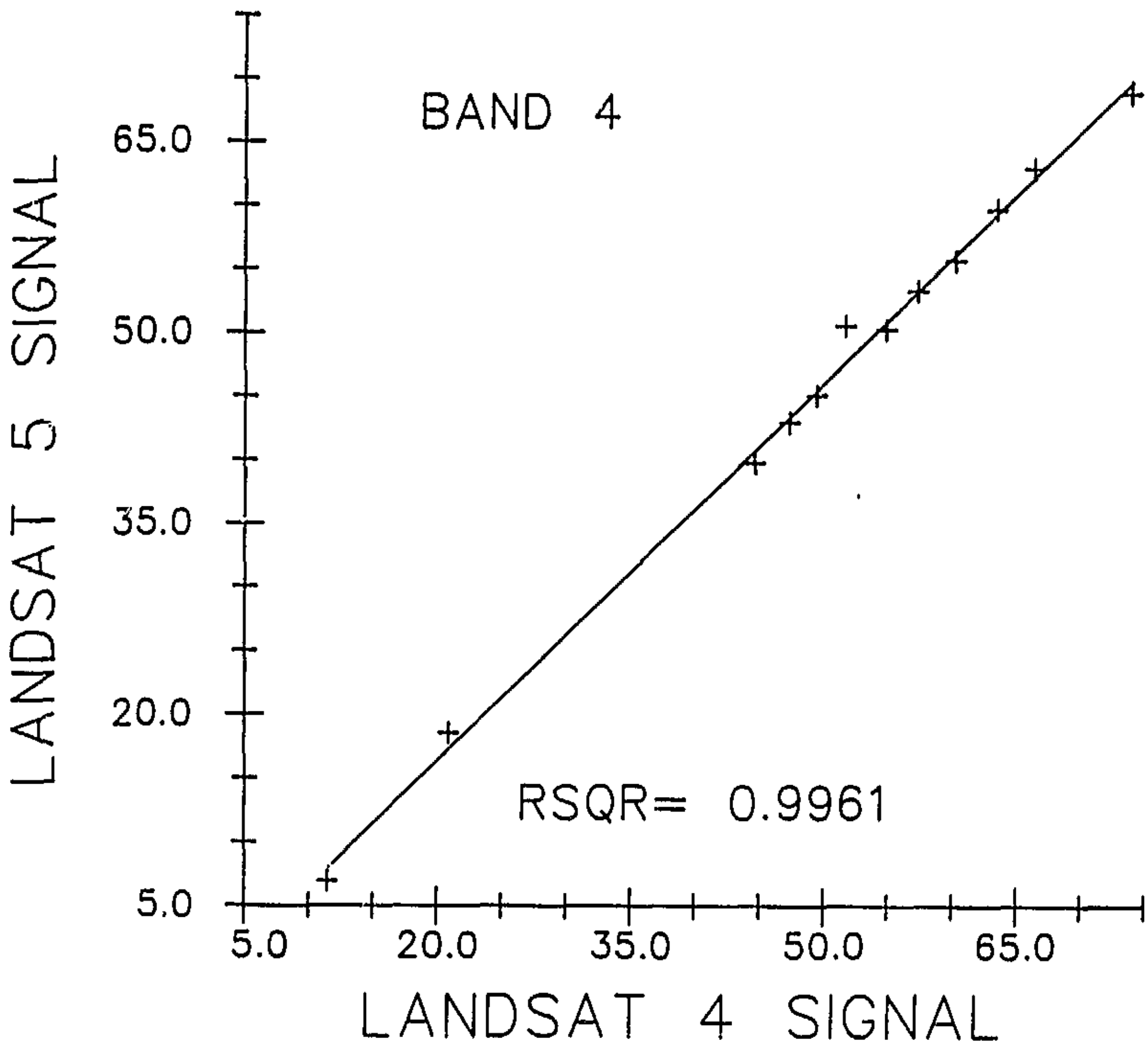

Figure 3(d). RELATIONSHIP BETWEEN LANDSATS-4 AND 5 TM CORRECTED DATA – BAND 4

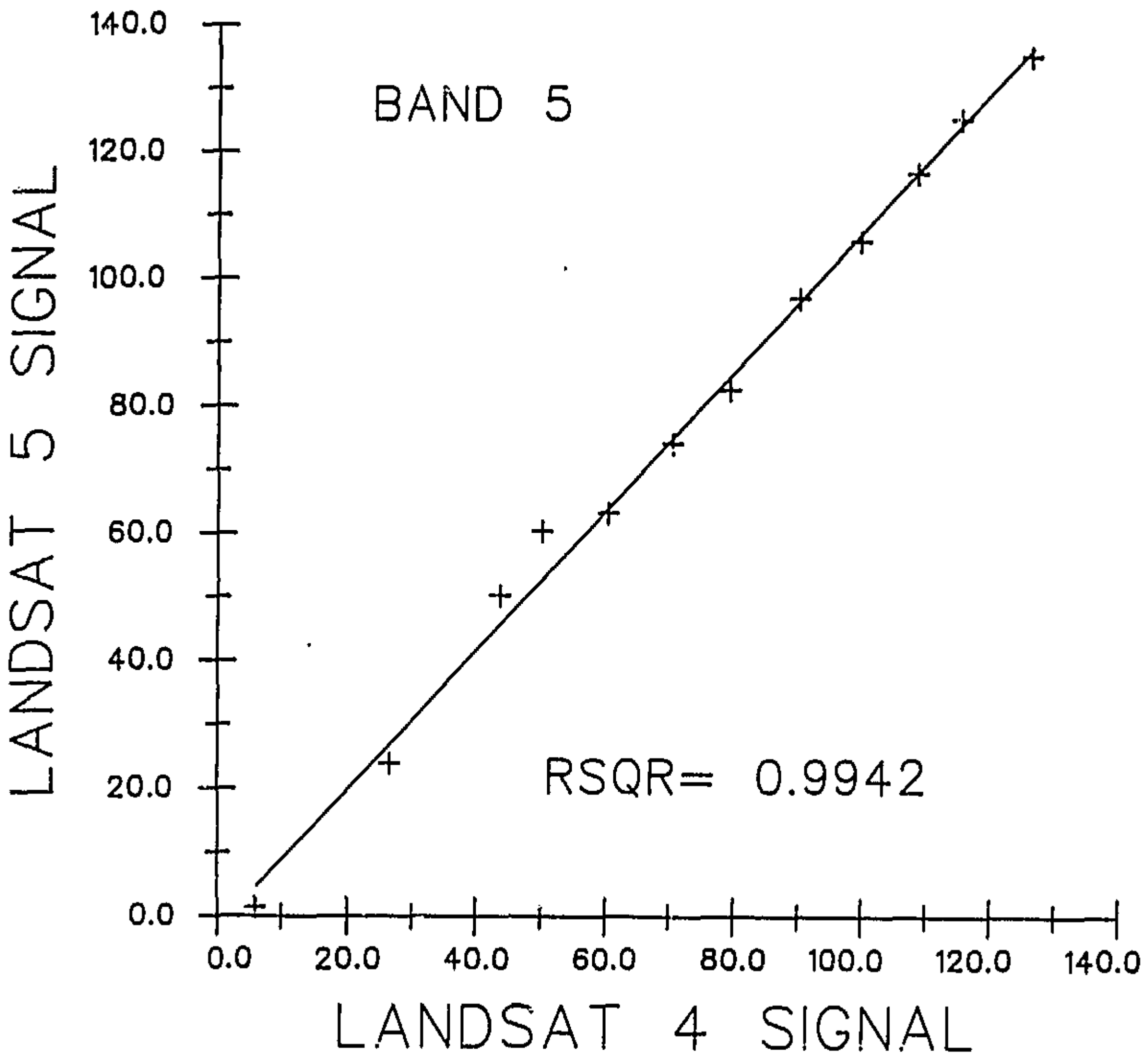

Figure 3(e). RELATIONSHIP BETWEEN LANDSATS–4 AND 5 TM CORRECTED DATA – BAND 5

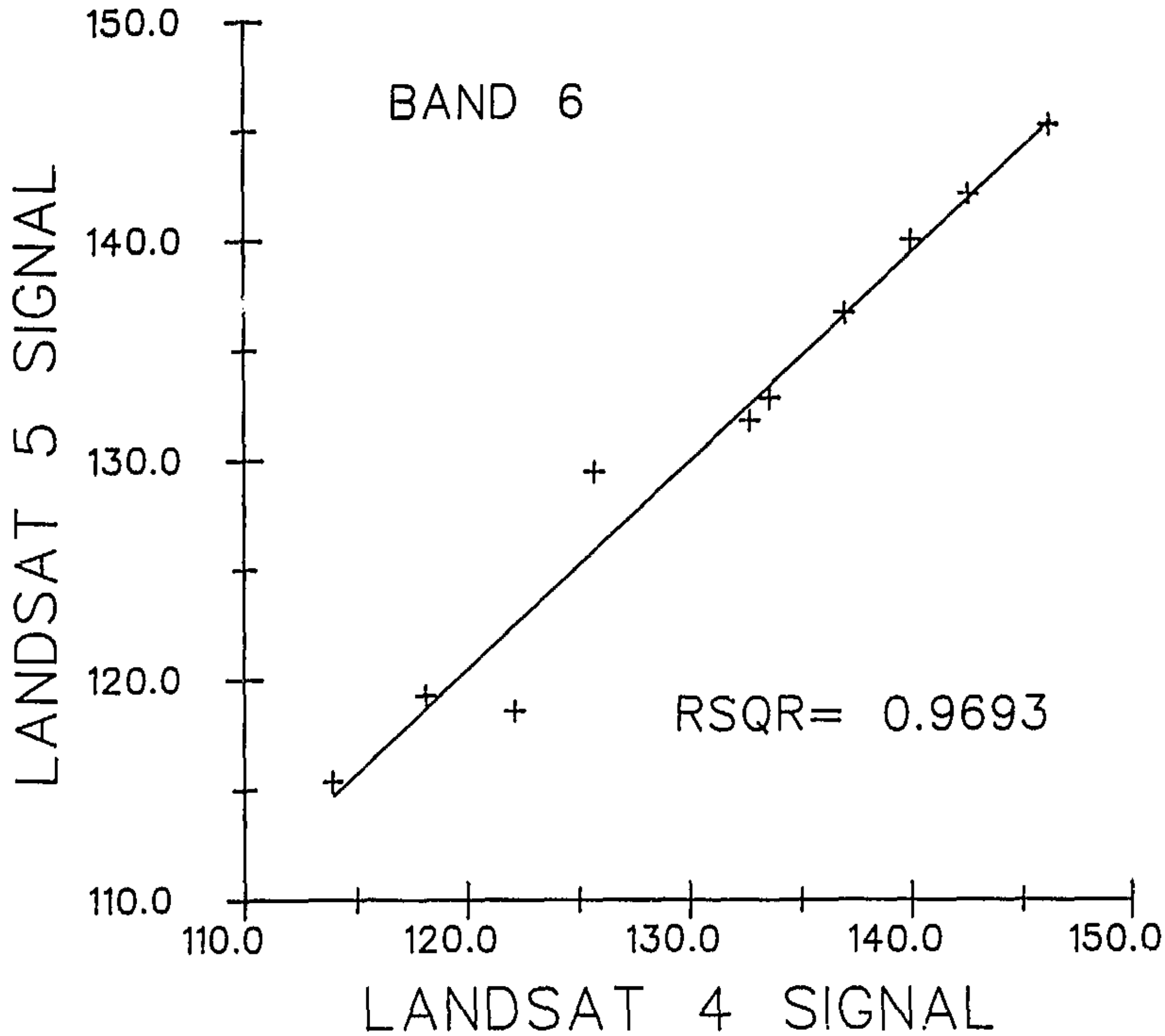

Figure 3(f). RELATIONSHIP BETWEEN LANDSATS-4 AND 5 TM CORRECTED DATA – BAND 6

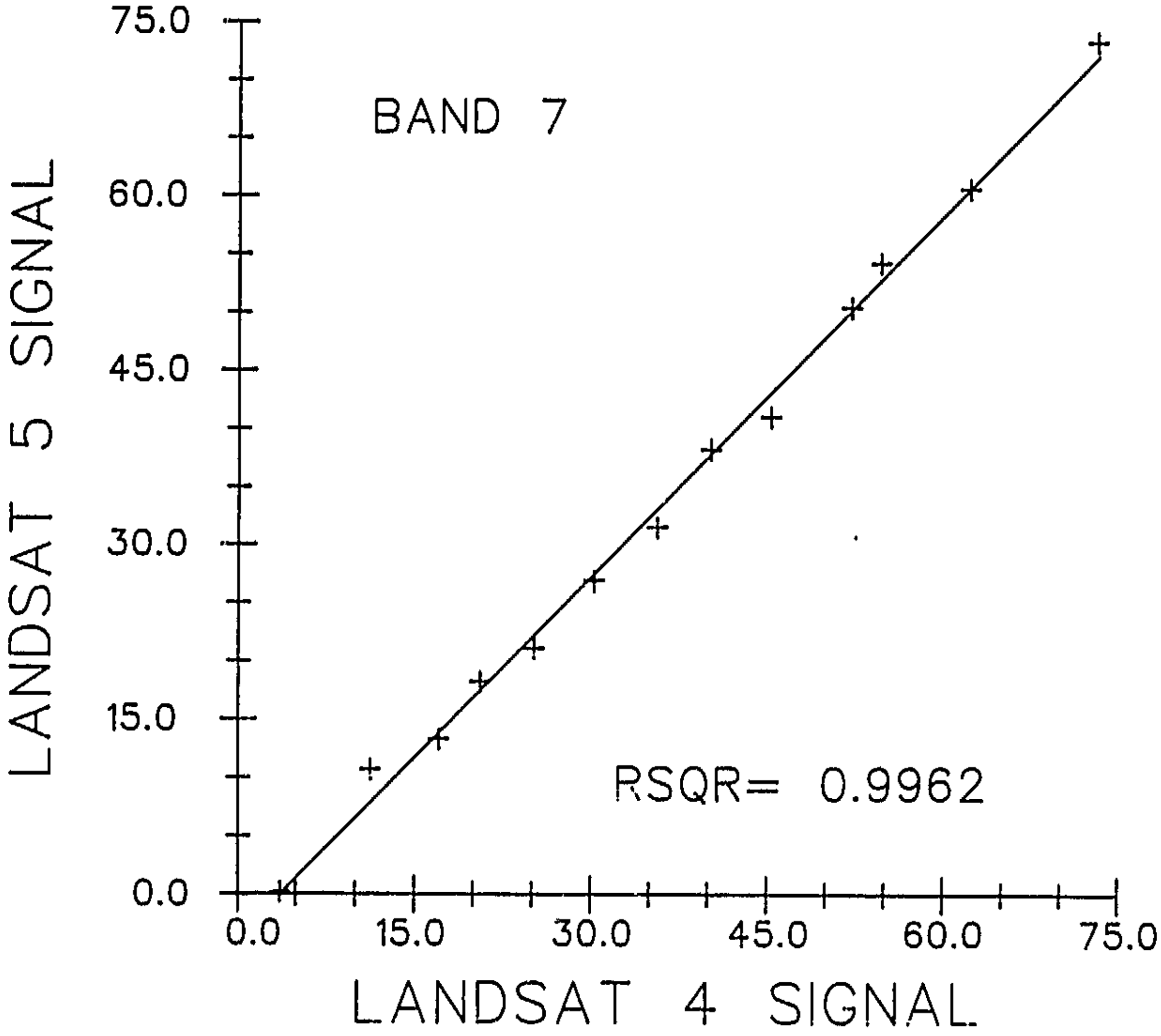

Figure 3(g). RELATIONSHIP BETWEEN LANDSATS-4 AND 5 TM CORRECTED DATA - BAND 7